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Belcher

[11] **3,795,169**

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[54] **ELECTRONIC DEVICE EMPLOYING A PHASE LOCKED LOOP FOR TUNING MUSICAL INSTRUMENTS**

[75] Inventor: **Donald K. Belcher,** Olathe, Kans.

[73] Assignee: **Signa-Signer, Inc.,** Fairfax, Va.

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[52] **U.S. Cl.** **84/454**

[51] **Int. Cl.** **G10g 7/02**

[58] **Field of Search** 84/454, 455, 456

[56] **References Cited**

UNITED STATES PATENTS

2,747,092	5/1956	Bostwick	84/456 X
3,509,454	4/1970	Gossel	84/454 X
3,722,352	3/1973	Ihrke	84/454

Primary Examiner—Lawrence R. Franklin

Attorney, Agent, or Firm—John J. Byrne

[57] **ABSTRACT**

An electronic tuner is used to indicate when a musical instrument is tuned above or below a desired given frequency. The disclosed elctronic tuner includes the following elements in series: an audio frequency microphone, a band pass filter selected to the frequency range desired, a preamplifier, a phase locked loop with associated power supply for detecting when the incoming frequency is above or below the desired frequency, an output amplifier, and a push-pull complementary transistor output means for driving a pair of lamps in such a fashion as to indicate whether the incoming frequency is above or below the desired frequency. Frequency discrimination is performed by the phase locked loop which is adjusted to a normal $B^{\flat}$ concert frequency of 466.2 Hz. The discriminating range of the phase locked loop may be varied according to the requirements of the instrument.

10 Claims, 4 Drawing Figures

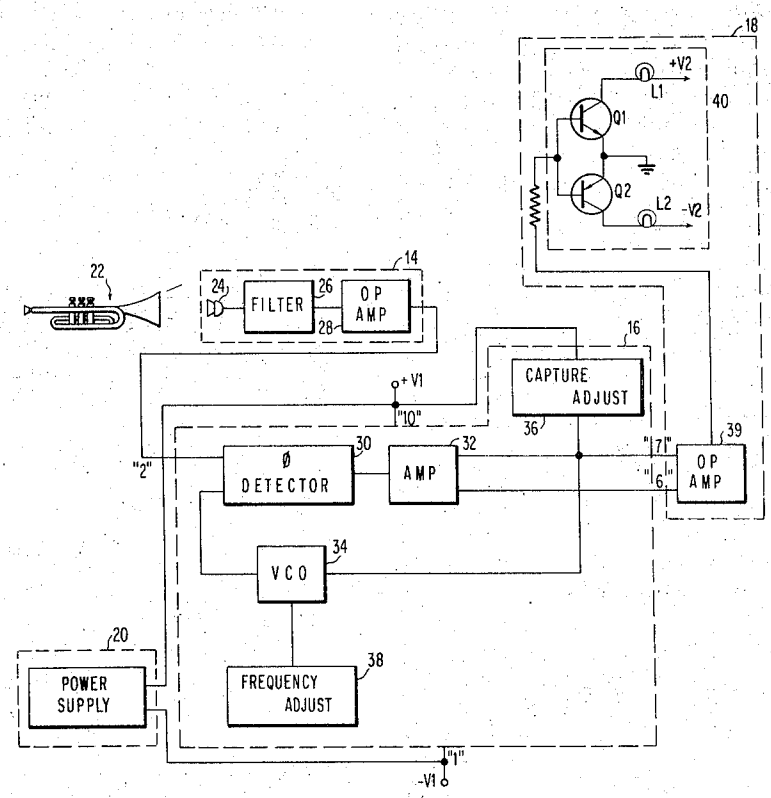


FIG. 1

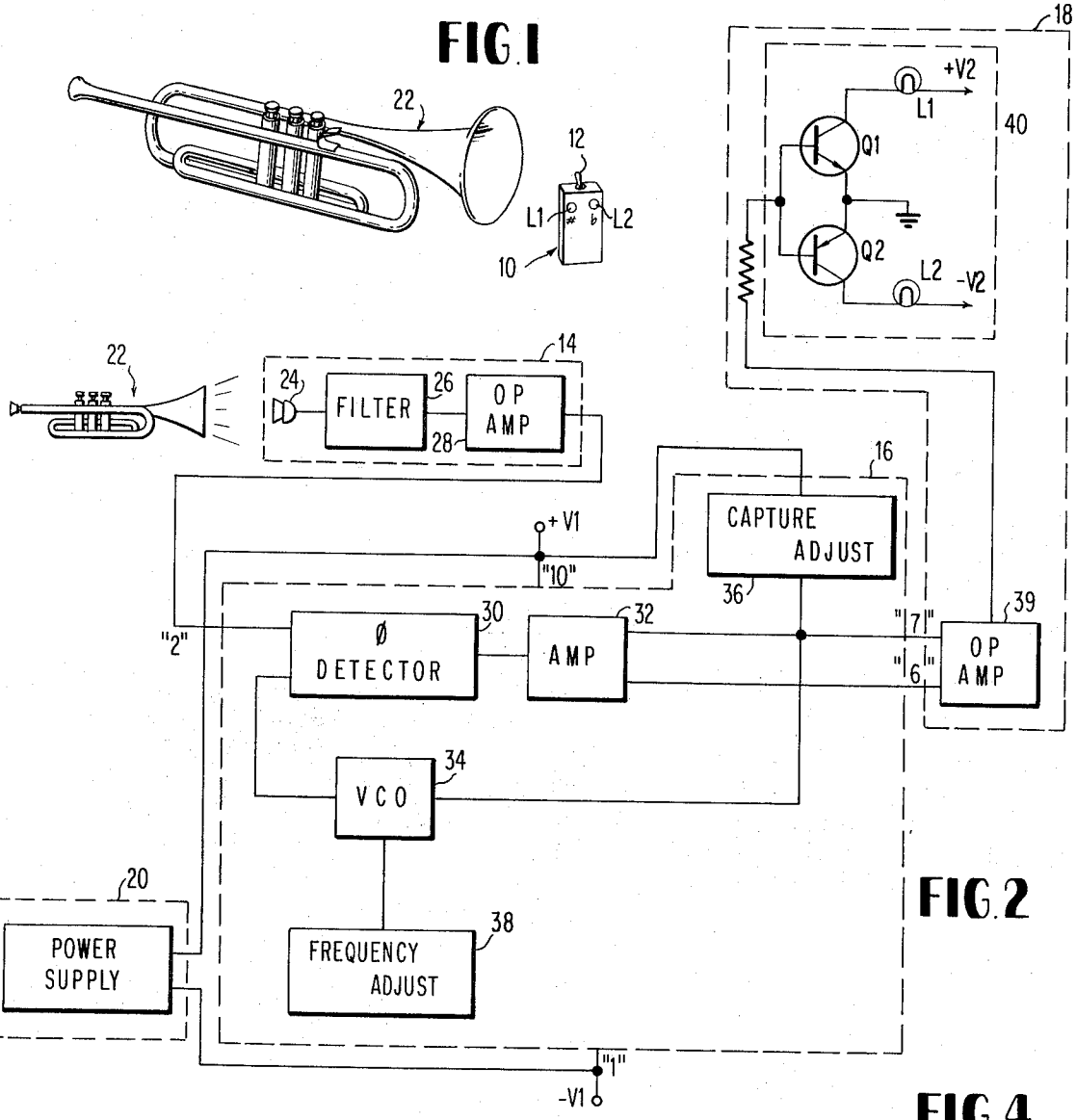
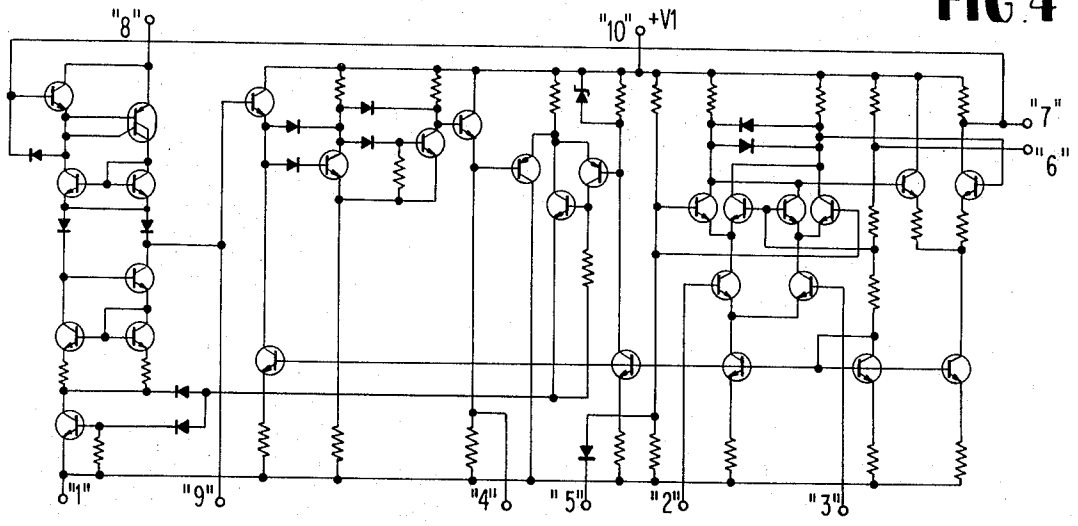


FIG. 2

FIG. 4



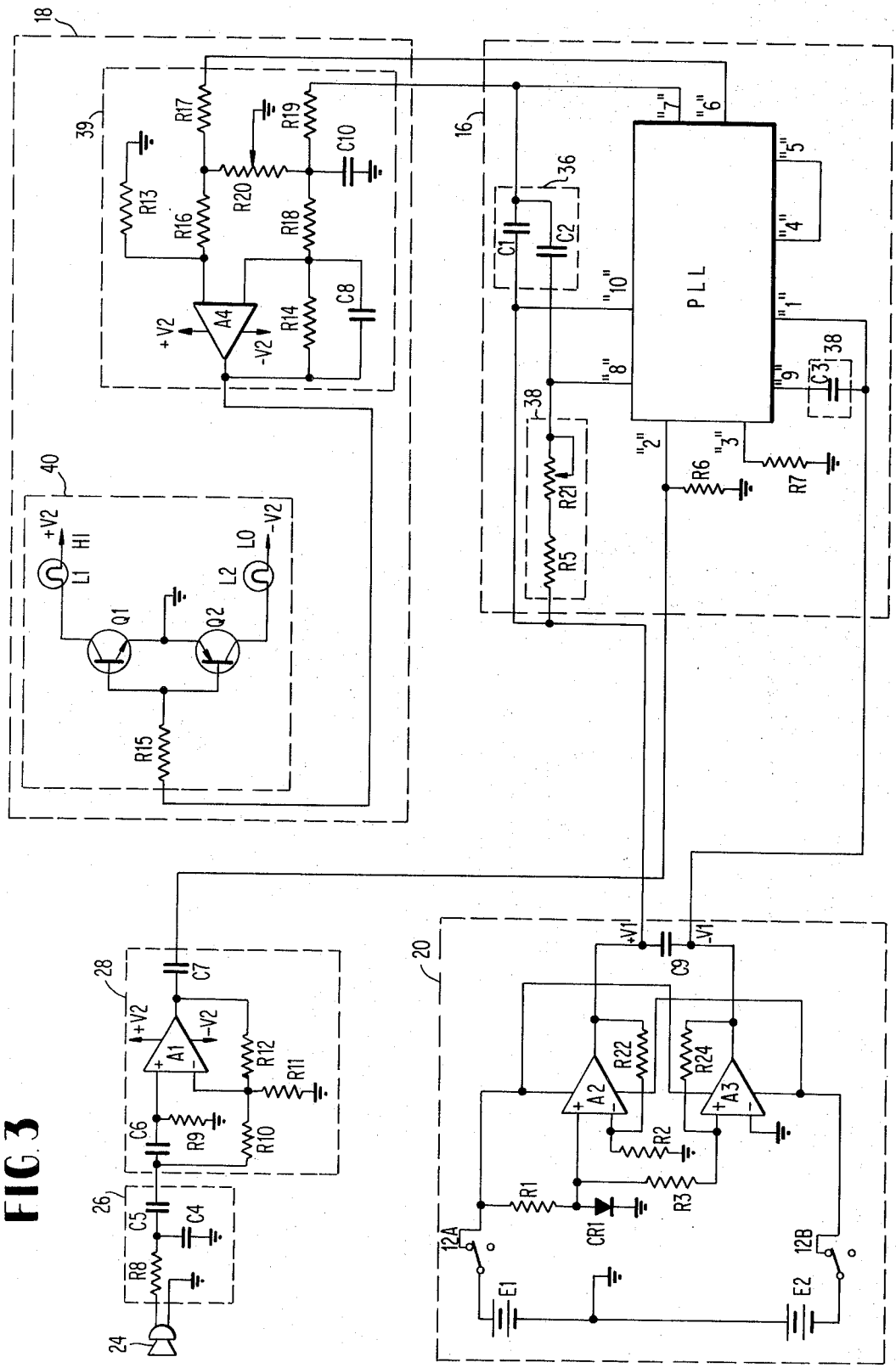

18
39
R17
R19
C10
R13
R20
R16
R18
A4
+V2
-V2
R14
C8
16
36
C1
C2
PLL
"7"
"6"
"5"
"4"
"10"
"1"
"8"
"9"
38
C3
"2"
"3"
R6
R7
R21
R5
40
+V2
HI
L1
L2
LO
-V2
Q1
Q2
R15
28
C7
A1
R12
R11
C6
R9
R10
26
C5
C4
R8
24
20
+V1
-V1
C9
A2
A3
R22
R24
R2
R1
R3
CR1
12A
12B
E1
E2

FIG 3

ELECTRONIC DEVICE EMPLOYING A PHASE LOCKED LOOP FOR TUNING MUSICAL INSTRUMENTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to tuners for musical instruments in general and to an electronic tuner employing a phase locked loop discriminator in particular.

2. Description of the Prior Art

Prior art music tuners frequently comprise tuning forks or similar mechanical frequency standards against which a musical note may be beat until the two frequencies are the same. Such mechanical devices are relatively crude in that they depend upon the human ear for verification. Furthermore, such mechanical standards may appreciably change frequency with changes in ambient conditions.

Typical prior art electronic tuners are disclosed in the patents to Gossel U.S. Pat. No. 3,509,454 and MacWorth-Young U.S. Pat. No. 3,631,756, in which a reference frequency is compared to the output frequency of a musical instrument in a phase comparator which produces an output proportional to the difference between the two frequencies. Unfortunately, such devices may not effectively discriminate against background noise and can be affected by heat. Another typical prior art device is the stroboscopic wheel such as disclosed by Dorf U.S. Pat. No. 2,919,620. Such devices tend to be relatively large and inconvenient for the average musician.

Applicant's invention includes the use of a phase locked loop which has the ability to seek and lock itself onto frequencies within its span of acquisition. Though phase locked loops have been used for purposes of FM modulation and discrimination such as disclosed by Henrion U.S. Pat. No. 3,221,260, their use in the context of musical tuners is novel and has definite advantages over prior art methods of musical tuning.

SUMMARY OF THE INVENTION

Briefly described, the electronic tuner of the instant invention includes an input circuit means including a microphone for detecting audio sounds in the musical range, a phase locked loop circuit connected to the output of the input means for locking onto frequencies within its band of acquisition, a power supply connected to said phase locked loop for providing power thereto, and an output means including a visual indicator connected to the output of the phase locked loop. The input circuit means can further include an operational amplifier and a band pass filter to help eliminate unwanted noise interference. The phase locked loop preferably further includes a means for adjusting the free-running frequency of an internal voltage control oscillator and, moreover, a low pass filter which may be adjusted to control the capture characteristics of the loop. The phase locked loop power supply is internally regulated so as not to adversely affect the operation of the phase locked loop (PLL). The output circuit includes an operational amplifier and a complementary push-pull amplifier in series which illuminate one or the other of a pair of indicator lights, depending upon whether the incoming audio frequency is above or below the free-running frequency of the voltage control oscillator of the PLL.

It is an object of the present invention to provide a small, compact, and convenient electronic tuner for musical instruments.

It is another object of the present invention to provide an electronic musical tuner which will lock itself to frequencies within its band of acquisition.

It is yet another object of the present invention to provide an improved electronic tuner which tends to ignore musical undertones and overtones and which will distinguish a pure musical note from extraneous audio noises that may be present.

Another object of the present invention is to provide a musical tuner which will couple tone information to a logic circuit such as a high precision piano tuner or which may be interfaced with an analog circuit, as in the preferred embodiment.

Still another object of the present invention is to provide an electronic tuner with the capture facilities of a PLL and which also includes the superior filter and audio processor characteristics thereof.

These and other objects and advantages of the invention will be more fully understood upon a reading of the following specification taken in view of the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a comparative illustration of the compact size of the electronic tuner of the present invention in relationship to a common musical instrument;

FIG. 2 is a block diagram of the electronic musical tuner of the present invention;

FIG. 3 is a detailed schematic diagram of the elements of the present invention; and

FIG. 4 is the schematic of a commercially available phase locked loop suitable for use in the circuit of FIGS. 2 and 3.

DESCRIPTION OF THE INVENTION

Unless otherwise indicated, like numbers refer to like elements in the different figures.

The finished electronic tuner of the instant invention is shown in FIG. 1. It is relatively small in size and simple in operation. The tuner unit 10 is shown having a master ON-OFF switch 12 and a pair of indicator lamps L1 and L2. To tune his instrument, a musician simply plays a note into tuner 10 and observes the reaction of the tuner on L1 and L2. If the note played is too high, light L1 will turn on. Likewise, if the note is too low, light L2 will turn on. If the musician is close enough to the preset center frequency (within approximately + or − 5Hz), then neither light will come on, indicating that the musical instrument is in tune.

A simplified block diagram of the electronic components is shown in FIG. 2. The block diagram of FIG. 2 shows the electronic tuner to be composed of the following series of elements: an input circuit means 14, a phase locked loop section 16, and an output section 18. The phase locked loop 16 is supplied with appropriate positive and negative voltages from power supply 20.

A musical instrument, illustrated here as being a trumpet, but being understood to represent all types of conventional tunable musical instruments, plays a single not into the input circuit 14. The single note is detected by microphone 24 and passed through band pass filter 26 and operational amplifier 28 to one input of phase detector 30 of phase locked loop circuit 16. Filter 26 is designed to select frequencies around the de-

sired tuning frequency and to reject other frequencies and overtones as noise.

Phase locked loop circuit 16 includes phase detector 30, amplifier 32, and voltage control oscillator 34. Optionally, it is shown as including a capture adjust circuit 36 and a frequency adjust circuit 38. Typically, the capture adjust circuitry comprises a low pass filter which determines the capture characteristics of the loop and is formed by an internal resistor and an external capacitor. The center frequency of the phase locked loop is determined by the free-running frequency of the voltage control oscillator (VCO). In practice, the center frequency of a phase locked loop VCO can be adjusted by means of an external resistor or a capacitor. The power supply 20 supplied an appropriate +V1 and −V1 voltage to phase locked loop circuit 16. Though the leads are shown as having an indefinite termination within the phase locked loop circuit 16 it is understood that power supply circuit 20 is only illustrative of the general concept of supplying power to a phase locked loop and that the specific connections within a conventional phase lock loop are well known to those of ordinary skill in the art.

Output circuit 18 includes an operation amplifier 39 connected in the differential mode. As is well known in the art, the output of such an amplifier will change polarity depending upon the relative voltage magnitude of the two inputs to the amplifier. Output circuit 18 further includes a visual indicator circuit 40. Circuit 40 includes a pair of complementary transistors connected with common emitters and common bases in a push-pull amplifier arrangement. When the incoming signal is negative, transistor Q1 will turn on and current will flow from source +V2 to light L1, transistor Q1, and to ground, thereby illuminating light L1. Conversely, when the incoming signal is negative, transistor Q2 will turn on and a circuit will be completed through source −V2, lamp L2, transistor Q2, and to ground, thereby illuminating lamp L2. Therefore, lamp L1 will be illuminated if the incoming voltage is positive and lamp L2 will be illuminated if the incoming voltage is negative. However, there is a small range near 0 volts in which it will not be possible to forward bias the base emitter junctions of either Q1 or Q1 sufficiently so that either one turns on. At this point, neither lamp L1 or L2 will be illuminated indicating that the note on the musical instrument is tuned to the desired frequency standard of phase locked loop circuit 16.

A detailed schematic of the assembly of the subcomponents found within the block diagram in FIG. 2 is shown in FIG. 3. Microphone 24 produces an electrical signal whose frequency is proportional to the audio frequency of the musical instrument. Microphone 24 may in practice be a speaker or other suitable transducer. The electrical signal passes through selective filter 26 which includes a coupler resistor R8, AC shunt capacitor C4, and AC coupling capacitor C5. The combination of C4 and C5 form a band pass filter which will discriminate against spurious signals outside of the desired band range. The signal from filter 26 is coupled via a capacitor C6 to one input of operational amplifier A1. Resistors R9, R10, R11, and R12 form part of the biasing and feedback circuitry associated with operational amplifier A1. Amplifier A1 is supplied with power from a voltage source represented as +V2 and −V2.

The filtered and amplified electrical signal emerging from amplifier 28 is coupled by capacitor C7 to input No. 2 of the phase locked loop (PLL). The details of the PLL are illustrated in FIG. 4 wherein the numbered pins in FIG. 3 correspond to associated pins in FIG. 4. Pins 2 and 3 are connected via resistors R6 and R7, respectively, to ground. A capacitor C3 is coupled between pins 1 and 9 of the PLL. Pin 1 represents the negative side of the power supply 20. C3 couples the negative supply −V1 to an input of the internal VCO 34 as illustrated in FIG. 2. C3 forms, along with resistors R5 and R21, the frequency adjust circuit 38. By selecting appropriate values of C3, R5 and R21, the free-running frequency of VCO 34 may be chosen. The free-running frequency of VCO 34 is selected to be the frequency standard to which the musical instrument is to be tuned. Pins 4 and 5 are jumpered and connect the output of the VCO 34 to the other input of phase detector 30. Pin 10 is connected directly to the positive side of power supply 20 +V1. Frequency control resistors R5 and R21, as previously discussed, are connected from −V1 to pin 8. Capacitor C1 is also connected between pin 10 and output pin 7. Likewide, capacitor C2 is connected between output pin 7 and pin 8. Together, C1 and C2 form the capture adjust circuit 36 and, together with an internal resistor, comprise a low pass filter which determines the capture characteristics of a loop.

The output signal from the PLL is taken from pins 6 and 7 and coupled to operation amplifier A4. The output from pin 6 is coupled directly via resistors R16 and R17 to the − input of A4; likewise, resistors R18 and R19 couple the output from pin 7 to the + input of A4. Output amplifier 38 further includes biasing and feedback elements R13 and R14, C8 and C10. C10 also serves as an AC shunt for spurious signals.

A balancing resistor R20 is located across the junction of R16 and R17 and the junction of R18 and R19. Operational amplifier A4 essentially operates as a differential amplifier whose sensitivity may be adjusted by R20. The output of A4 is coupled via resistor R15 to the input of visual indicator circuit 40 which comprises a pair of complementary push-pull transistors Q1 and Q2 with emitters and bases connected together. The collectors of Q1 and Q2 are connected via lamps L1 and L2, respectively, to voltage sources +V2 and −V2.

Power supply 20 is a regulated power supply for providing relatively stable temperature independent power to the phase locked loop circuit 16. Power supply 20 includes a set of series connected batteries E1 and E2, whose common junction is connected to ground. Those two batteries are connected to switch means 12A and 12B corresponding to switch 12 seen in FIG. 1. When switches 12A and 12B make contact, power from batteries E1 and E2 is supplied to cross-coupled amplifiers A2 and A3. Associated with amplifiers A2 and A3 are a pair of feedback resistors R22 and R4, respectively. Part of the power from battery E1 is coupled via resistor R1 to the positive input of A2 and through resistor R3 to the negative input of A3. Diode CR1 serves as a shunt for positive signals to ground and also as a reference voltage point. Amplifiers A2 and A3 are cross-coupled in a conventional manner and their regulated output is applied across filter capacitor C9. C9 helps to smooth the output of power supply 20.

In operation, power supply 20 acts in a conventional manner to supply regulated power to phase locked loop circuit means 16.

In typical operation, the voltage control oscillator **34** within phase locked loop circuit means **16** is preadjusted via elements **R5, R21** and **C3** to a free-running frequency corresponding to the goal or desired frequency of the instrument. Though other frequencies can be used, it has been found desirable to use as a center frequency the B concert note of 466.2 Hz. Therefore, in operation, phase locked loop circuit means **16** is adjusted to have the free-running frequency of VCO **34** set to 466.2 Hz.

As an illustrative example, it will be presumed that the VCO is set to 466.2 Hz. and that a musical note higher than concert B is played into microphone **24.** Microphone **24** then converts this high note to an electrical signal and passes it through filter **26** which eliminates spurious overtones and noise. This relatively pure note is then passed on to amplifier circuit **28** where it is amplified and coupled via capacitor C7 to input terminal **2** of the PLL. Since the frequency at pin **2** is different than the frequency on the other input of the phase detector **30** at pin **5,** there will be an output from the phase detector that is proportional to the difference between the two frequencies. This signal is then amplified by element **32** and coupled to VCO **34** where it will tend to drive the output frequency of VCO **34** in such a direction as to make it coincide with the frequency at pin **2.** In other words, the operation of phase detector **30** is such that it will cause VCO **34** to produce an output frequency that will follow the input frequency on pin **2.** The speed with which VCO **34** follows the input frequency on pin **2** is determined by the value of capacitors C1 and C2 to capture adjust circuit means **36.** If, as is the illustrated case, the frequency at pin **2** is higher than the immediate frequency at pin **5,** the output at pin **6** will be higher than the output at pin **7.** If, alternatively, the musical audio frequency played into microphone **24** is lower than concert B , then the output of pin **6** would be lower in voltage than that of pin **7.** Due in part to its rapid capture ability, a PLL is superior in this context to other types of demodulators. In particular, it possesses better filter and audio processor characteristics.

The output of the phase locked loop pins **6** and **7** is coupled to operational amplifier A4 which performs in the differential mode. Since pin **6** is higher in voltage than pin **7** in the illustrated example, the output from differential amplifier A4 is positive. A positive voltage signal is then coupled to the input bases of Q1 and Q2. Since Q1 and Q2 are complementary, only Q1 will turn on when a positive signal is applied to its base and only Q2 will turn on when a negative signal is applied to its base. Therefore, in the illustrated example, a positive signal will turn on transistor Q1 thereby illuminating light L1 which indicates that the incoming musical frequency is higher than concert B . Conversely, an input musical frequency lower than concert B will turn on light L2 but not light L1. In this manner, a musician can use the lights to tune his instrument to the appropriate range. When the incoming audio frequency is near enough to the preset center frequency, generally within + or − 5Hz, then neither light will come on, thereby indicating that the musical instrument is in tune.

As discussed previously, the purpose of power supply **20** is to provide a regulated, smooth, continuous, and ripple-free pair of complementary voltages +V1 and −V1 to phase locked loop circuit means **16.**

FIG. 4 is a detailed schematic of a Signetics SE/NE 565 phase locked loop linear integrated circuit of the type found satisfactory with the disclosed embodiment. Obviously, other phase locked loop circuits could be used when connected in a manner known to those of ordinary skill in the art.

The following is a parts list of the elements shown in FIG. 3.

RESISTORS

(All resistors are 1/4 watt, 5% tolerance unless otherwise specified)

R1 — 10K ohms
R2 — 6.8K ohms
R3 — 6.8K ohms
R4 — 75K ohms
R5 — 13.0K ohms (RN 65C)
R6 — 6.8K ohms
R7 — 6.8K ohms
R8 — 2.2K ohms
R9 — 100K ohms
R10 — 10K ohms
R11 — 1K ohms
R12 — 100K ohms
R13 — 470K ohms
R14 — 470K ohms
R15 — 270K ohms
R16 — 10.0K ohms
R17 — 1.00K ohms
R18 — 10.0K ohms
R19 — 1.0K ohms
R20 — 50K ohms (potentiometer, Bourns 3359P)
R21 — 5K ohms (potentiometer, Bourns 3359P)

CAPACITORS

C1 — 0.1MF ceramic disc Sprague TG-S10
C2 — .00MF ceramic disc Aerovox GPDX5F 102K
C3 — .047 MF polystyrene Mallory No. SXL 147 C4 — .14 MF 35 volt 20 percent tolerance ITT TAG
C5 — .05 MF ceramic disc Sprague TG-S50
C6 — .0039 MF ceramic disc Sprague No. 5GA-D39
C7 — .05 MF ceramic disc Sprague No. TG-S50
C8 — .047 MF ceramic disc Sprague No. HY-435
C9 — .047 MF ceramic disc Sprague HY-345

SPECIALIZED COMPONENTS

CR1 (diode) — 1N2069
A1, A2, A3, A4 — Dual operational amp. 747
PPL — SE-565A Signetics
Q1 — 2N5223
Q2 — 2N5227
Mike 24
Speaker — SPECO No. UT 108
L1 and L2 — Chicago Minn., CN 26-3-05-14
Switch 12 — CNK No. 7207

It would be obvious to one of ordinary skill in the art that changes and modifications are possible without departing from the spirit of the disclosed embodiment. For instance, a regular dynamic or crystal microphone could be used instead of a speaker in place of element **12.** It is well known in the art that a wide variety of acoustical transducers would be appropriate as microphones. Moreover, though amplifiers A1 and A4 are highly desirable in this particular application, they are by no means necessary and it may be possible or desirable to operate without them. Even though amplifier A4 is not absolutely necessary in the context of this particular invention, it has been found to be advantageous in controlling the sensitivity of the two output lamps. The sensitivity of the output indicator lamps can

be cut from ± 5.0 Hz to ± 2.5 Hz by simply doubling the value of R14. This additional control over the sensitivity of the tuning instrument is a highly desirable feature where musical accuracy is important. Likewise, band pass filter section 26 improves the selectivity of the entire circuit and cuts out extraneous noise and overtones but may not be entirely necessary.

The choice of B as the center frequency of the phase lock loop was based on the fact that this particular note is very popular among bands and musical groups. As a practical matter, many other frequencies could be chosen depending on the requirements of the instrument or instruments being used. The adjustment of the phase lock loop to another musical frequency is accomplished by changing the values of capacitor C3 or resistors R5 and/or R21.

Power supply 20 provides regulated, smooth voltage to the PLL and contributes greatly to its accuracy. If accuracy is not highly important, it would, of course, be possible to work with a cruder, unregulated power supply or a power supply of a different nature.

Visual indicator 40 is one of a variety of suitable indicators that could be used. For instance, it would be possible, of course, to use a meter or some other type of display device. However, it has been found in practice that the two lamp method employed in this invention is very well suited for this kind of device. The use of two lamps is a simple and effective means of indicating the output from the PLL. Even though a meter could be used in place of the two indicating lamps it is well known that a meter movement is not as physically rugged as are lamps nor can they be seen from as far away. For this reason, the use of indicator lamps is much preferred over the use of conventional meters. Furthermore, other types of phase locked loops which are well known in the art may be usable in this particular environment.

In a general manner, while there have been disclosed effective and efficient embodiments of the invention, it should be well understood that the invention is not limited to such embodiments as there might be changes made in the arrangemenet, disposition, and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

I claim:

1. An electronic tuning device for aiding in tuning a musical instrument, comprising;

an input circuit for receiving a signal having a frequency in the musical range,

a phase locked loop circuit responsive to said input circuit and having an output, said phase locked loop circuit including a reference frequency oscillator for generating a reference center frequency, a phase detector for receiving said signal and providing an output proportional to the difference between said signal frequency and said center frequency, and a feedback loop from said detector to said oscillator for driving said oscillator to said signal frequency,

a power supply circuit means connected to said phase locked loop circuit for providing power thereto,

and an output circuit means connected to said phase locked loop output and including a visual indicator for indicating when said signal is above or below said center frequency.

2. The apparatus of claim 1 wherein said reference frequency oscillator is a voltage control oscillator having an adjustable free running frequency corresponding to said reference center frequency.

3. The apparatus of claim 2 wherein the free-running frequency of said voltage control oscillator is 466.2Hz.

4. The apparatus of claim 1 wherein said phase locked loop circuit includes a capture adjust circuit for determining the band of acquisition of said phase locked loop.

5. The apparatus of claim 1 wherein said input circuit includes a microphone means connected in series with a band pass filter and an amplifier, said band pass filter being tuned to pass said musical frequency signal.

6. The apparatus of claim 1 wherein said phase looked loop further includes,

an amplifier having an input and an output, the input of said amplifier being connected to the output of said phase detector and the output of said amplifier being connected to the output of said phase locked loop and to the input of said reference frequency oscillator.

7. The apparatus of claim 6 wherein said amplifier produces a pair of voltage outputs proportional to the output of said phase detector.

8. The apparatus of claim 7 wherein said output circuit means includes a differential amplifier having a pair of input terminals each connected to receive said voltage outputs from said phase locked loop amplifier, said differential amplifier including an output terminal, and wherein said visual indicator has an input terminal connected to the output terminal of said differential amplifier.

9. The apparatus of claim 8 wherein said visual indicator comprises,

an NPN transistor having a base, collector, and emitter,

a PNP transistor having a base, collector, and emitter,

the bases of both of said transistors being connected together and forming said visual indicator input terminal and the emitters of both of said transistors being connected together to a common ground,

a pair of lamps,

a positive lamp power supply, and

a negative lamp power supply,

wherein one of said lamps is connected between the collector of said NPN transistor and said positive power supply and the other of said lamps is connected between the collector of said PNP transistor and said negative power supply.

10. The apparatus of claim 1 wherein said power supply circuit means is a regulated power supply including a pair of cross-coupled amplifiers for producing a pair of positive and negative voltages for said phase locked loop.

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